Nutritive Value of Virginia Wildrye, a Cool-Season Grass Native to the Northeast USA

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ABSTRACT

Interest in native plant species for conservation and production has increased because of new federal policies. We evaluated accessions of the native cool-season grass Virginia wildrye (*Elymus virginicus* L.) from the northeastern USA for nutritive value and its association with plant morphological traits. Thirteen accessions, one cultivar (Omaha), and one commercial ecotype of *Elymus* were transplanted into single-row field plots in late summer of 2000 at Beltsville, MD, Rock Springs, PA, and Big Flats, NY. Two orchardgrass (*Dactylis glomerata* L.) cultivars were included. Primary growth was harvested in April (Beltsville) or May (Rock Springs and Big Flats) of 2001 and 2002 and analyzed for neutral detergent fiber (NDF), crude protein (CP), and digestible NDF (dNDF). Nutritive value measures were related to plant morphological attributes [leaf width, length, area, and leaf-to-stem mass ratio (LSR)]. Virginia wildrye accessions differed ($P < 0.01$) in nutritive value and often had lower NDF and higher CP and dNDF than the commercial ecotype, Omaha cultivar, and orchardgrass. The LSR accounted for most of the variation in nutritive value. Orchardgrass was more mature at harvest than *Elymus* entries and thus lower in nutritive value. Neutral detergent fiber was negatively correlated with LSR ($r = -0.26$ to -0.74, $P < 0.05$), whereas CP and dNDF were positively correlated ($r = 0.36$ to 0.80 for CP and 0.44 to 0.74 for dNDF, $P < 0.05$). Neutral detergent fiber was also positively correlated ($r = 0.27$ to 0.86, $P < 0.05$) with leaf length. Virginia wildrye is comparable to other cool-season grasses in nutritive value.

Most forage grasses grown in the northeastern USA are introduced species such as orchardgrass, bluegrass (*Poa* spp.), or tall fescue (*Festuca arundinacea* Schreb.). Native warm-season perennials, such as switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman), account for most of the native grasses used in forage systems. Few, if any, native cool-season grasses have been evaluated as potential forage species in the northeastern USA. New federal policies related to invasive species, conservation plantings, and farm programs have created greater interest in native plants for conservation and production during recent years (Richards et al., 1998; Federal Register, 1999).

Virginia wildrye, a perennial cool-season grass native to the northeastern USA, grows along streams, forest margins, and in other moist areas (Pohl, 1947; Hitchcock, 1971). It is recommended as a component in some conservation plantings for revegetation. Asay and Jensen (1996) considered Canada wildrye (*E. canadensis* L.), blue wildrye (*E. glaucus* Buckley), and Dahurian wildrye (*E. dahuricus* Turcz ex Greiseb) the most noteworthy of the *Elymus* wildryes as forages and briefly mentioned Virginia wildrye for revegetating prairie (Asay and Jensen, 1996). Closely related, both Virginia wildrye and Canada wildrye are highly self-fertile allotetraploids ($2n = 28$) with the SSHH genome constitution (Asay and Jensen, 1996). Very little breeding has been done in either species. In an evaluation of 30 grass species in Saskatchewan, Canada, Virginia wildrye was considered a promising forage grass, but lack of winter hardiness limited its persistence (Lawrence, 1978). Hereafter in this paper, the terms *"Elymus"* and "wildrye" will refer to *E. virginicus*.

Genetic variation for nutritive value occurs within many species of cool-season introduced grasses (Casler et al., 1996). Sometimes the variation in nutritive value results simply from differences in maturity or plant morphology. For example, the LSR of grasses typically declines with maturity and is accompanied by a decrease in nutritive value (Nelson and Moser, 1994). Nutritive value of grasses, however, can be improved by changing the cell wall composition without affecting plant maturity or gross morphology [e.g., in smooth bromegrass (*Bromus inermis* Leyss); Casler and Carpenter, 1989]. Plant morphology can influence other traits related to livestock performance. For example, leaf width in tall fescue was negatively related to leaf tensile strength and, hence, positively related to preference by grazing cattle (MacAdam and Mayland, 2003).

Greater interest in the use of native grass species in conservation and other plantings has created a need for more information on the suitability of locally adapted native species for the northeastern USA. We could not find any information on the nutritive value of *Elymus* as a forage grass in the northeastern USA. Previously, we reported on the productivity, morphology, and persistence of several *Elymus* accessions at three locations in the northeastern USA (Sanderson et al., 2004). Our objective in this study was to evaluate the same northeastern accessions of Virginia wildrye for nutritive value.

MATERIALS AND METHODS

The experiment was conducted at the USDA-NRCS Plant Materials Center in Big Flats, NY (42°N, 76°54′W, elevation 290 m), the Russell E. Larson Agricultural Research Center at Rock Springs, PA (40°48′N, 77°52′W, elevation 365 m), and the USDA-NRCS National Plant Materials Center in Beltsville, MD (39°02′N, 76°56′W, elevation 36 m) during 2000 to 2002. Soil types were Unadilla silt loam (coarse-silty, mixed, active, mesic Typic Dystrudepts) at Big Flats, Hagerstown silt

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; dNDF, digestible neutral detergent fiber; IVTD, in vitro true digestibility; LSR, leaf-to-stem mass ratio; NDF, neutral detergent fiber; SLA, specific leaf area.

Table 1. Origin of Virginia wildrye accessions evaluated.

Accession or cultivar	State	County	Date collected
9085137	Maryland	Allegany	August 1998
9085141	Maryland	Montgomery	September 1998
9085127	Maryland	Washington	August 1998
NJPMC	New Jersey		1999
9051780	New York	Canojoharie	September 1999
9051781	New York	Tompkins	September 1999
9051783	New York	Montgomery	September 1999
9051784	New York	Cortland	September 1999
9051785	New York	Madison	September 1999
9051786	New York	Chemung	September 1999
9051777	Vermont	Caledonia	September 1998
9051778	Vermont	Chittenden	September 1998
9051779	Vermont	Chittenden	September 1999
Commercial ecotype	Pennsylvania	Crawford	
Omaha	Nebraska		

loam (fine, mixed, semiactive, mesic, Typic Hapludalfs) at Rock Springs, and Iuka sandy loam (coarse, loamy, siliceous, active, acid, thermic, Aquic Udifluvents) at Beltsville.

The Virginia wildrye accessions were collected by the USDA-NRCS plant materials centers from several northeastern states in 1998 and 1999 (Table 1). Thirteen accessions and two commercial sources (the cultivar Omaha from Stock Seed Co., Murdock, NE; and a Pennsylvania ecotype sold by Ernst Conservation Seeds of Meadville, PA) of wildrye were transplanted into single-row field plots during August 2000 at Beltsville and September 2000 at Rock Springs and Big Flats. Two orchardgrass cultivars (Potomac and Pennlate) were included for comparison. Seedlings of each entry were started in the greenhouse at the National Plant Materials Center, Beltsville. Entries were hand transplanted into single-row plots of 10 plants per plot. Each plot of 10 plants contained eight experimental plants and a border plant of wildrye at each end of the row. Border rows of Omaha wildrye alternated with row plots of the accessions. Plants were spaced 30 cm apart within rows, and rows were spaced 30 cm apart. At each location, a plastic weed barrier controlled weed seedlings during establishment. The plastic weed barrier was removed from all plots in March (Beltsville) or April 2001 (Big Flats and Rock Springs) after which weeds were controlled by hand and with herbicides.

Soil pH (to a 15-cm depth) was 5.7 at Big Flats, 6.5 at Rock Springs, and 6.1 at Beltsville. Soil P (determined by soil test on 0- to 15-cm deep soil samples) was above optimum at each location, whereas soil K was below optimum. Potassium fertilizer (0–0–60) was applied at 40 kg K ha^{-1} at each location in April 2001. Nitrogen (as ammonium nitrate) was applied at 56 kg ha^{-1} at green-up (late March or early April) in the spring and after the second harvest each year.

Plots were harvested on 22 May at Big Flats and 20 May at Rock Springs in 2001 and 2002. Harvests were on 26 April 2001 and 23 April 2002 at Beltsville. Relative maturity was determined visually on a 1 to 8 scale (Casler and Van Santen, 2000). *Elymus* accessions were at the late vegetative (leaf sheaths or stem internodes elongated to just before boot stage) developmental stage at all harvests, whereas orchardgrass was headed. Six experimental plants in each row were clipped to a 7-cm height, placed in cloth bags, and dried at 55°C for 48 h. The plot was discarded for yield purposes if fewer than four experimental plants were alive. At Rock Springs, plots in one block were severely damaged by the bluegrass billbug (*Sphenophorus parvulus* Gyllenhal); therefore, this block was discarded.

At the first harvest each year, 10 tillers of similar morphological developmental stage were taken from the experimental plants in each row. The number of leaves was counted on each tiller and the length and width of each fully elongated leaf blade was measured and leaf area calculated with a laser area meter (CID model CI-203, CID Devices Inc., Vancouver, WA). After measurements, the leaf blades and stems (including the leaf sheath) were dried at 55°C for 48 h, weighed, and the specific leaf area (SLA, cm^2 leaf area g^{-1} leaf mass) and LSR calculated. Leaf length, width, and SLA data were presented in Sanderson et al. (2004).

Forage samples from the first harvest at each location were analyzed for nutritive value via calibrated near infrared reflectance spectroscopy by the Crop Quality Laboratory at the Pennsylvania State University. Calibration samples were analyzed for NDF, in vitro true digestibility (IVTD; 48 h fermentation) and CP by a commercial laboratory (DairyOne, Ithaca, NY). Detergent fiber and IVTD procedures were according to Van Soest and Robertson (1980). Digestible NDF was calculated from NDF and IVTD values. Nitrogen was determined by the Dumas combustion method (AOAC, 1990) and CP calculated as N $\times$ 6.25. Calibration statistics were: CP, standard error of prediction corrected for bias [SEP(C)], 7.4; R^2, 0.99; NDF, SEP(C), 8.8; R^2, 0.88; IVTD, SEP(C), 15.7; R^2, 0.88.

The experiment was a randomized complete block design with four blocks at Big Flats and Beltsville and three blocks at Rock Springs. Plot means were used in the analysis of variance. A combined analysis across years and locations was done on all data. Years and locations were considered random effects and the accessions were considered fixed effects. The MIXED procedure in SAS (1998) was used to perform the analysis. Denominator degrees of freedom were calculated using the Satterthwaite option of MIXED analysis to determine appropriate degrees of freedom to test fixed effects and interactions of fixed effects. Planned contrasts were used to compare means. The contrasts were (i) average of *Elymus* entries vs. average of orchardgrass cultivars, (ii) average of New York accessions vs. average of Omaha and the commercial ecotype, (iii) average of Maryland accessions vs. average of Omaha and the commercial ecotype, (iv) the accession NJPMC vs. average of Omaha and the commercial ecotype, and (v) average of Vermont accessions vs. average of Omaha and the commercial ecotype. Spearman's rank correlations were used to examine changes in the relative performance of accessions and cultivars among years and locations. Pearson's product moment correlations were used to determine associations between nutritive value characteristics and morphological traits [leaf area, length, width, SLA, and LSR; reported in Sanderson et al., 2004]. Statistical significance was declared at the $P < 0.05$ level unless otherwise noted.

RESULTS AND DISCUSSION

Entry (accession or cultivar) $\times$ year interactions were significant for NDF, CP, and dNDF at Big Flats and Rock Springs, but not Beltsville. The interactions were an order of magnitude lower than the main effect of entry and were caused mainly by changes in magnitude of values between years and minor changes in rank among a few entries. Environmental interactions for nutritive value often are minor in evaluating perennial forages (Casler and Vogel, 1999) therefore we present nutritive value data as means across years within locations.

Significant differences were found between *Elymus* and orchardgrass and among the *Elymus* accessions for nutritive value (Tables 2, 3, and 4). Orchardgrass had higher concentrations of NDF and lower concentrations of CP and dNDF (except at Beltsville) than the *Elymus*

Table 2. Concentrations of neutral detergent fiber in Virginia wildrye accessions and two orchardgrass cultivars at three locations. Data are the least squares means of 2 yr at each location.

Origin	Accession or cultivar	Big Flats	Beltsville	Rock Springs
		— g kg^{-1} dry matter —		
Maryland	9085137	491	432	
	9085141	506	436	462
	9085127	501	446	451
	Mean	499	438	456
New Jersey	NJPMC	476	462	444
New York	9051780	552	472	499
	9051781	534	463	486
	9051783	540	460	495
	9051784	549	463	502
	9051785	504	454	470
	9051786	519	453	491
	Mean	533	461	491
Vermont	9051777	534	450	493
	9051778	522	461	482
	9051779	484	407	440
	Mean	513	439	472
Elymus checks	Commercial ecotype	543	468	488
	Omaha	514	453	462
	Mean	528	460	475
Orchardgrass	Pennlate	590	501	601
	Potomac	616	499	605
	Mean	603	500	603
Elymus mean		518	452	478
SE		4.9	5.2	8.4
	Contrasts†			
Elymus vs. orchardgrass		**	**	**
NY vs. checks		NS	NS	**
NJPMC vs. checks		**	NS	**
MD vs. checks		*	**	*
VT vs. checks		**	**	**

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: *Elymus* vs. orchardgrass, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. checks, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. checks, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. checks, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. checks, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

Table 3. Concentrations of crude protein in Virginia wildrye accessions and two orchardgrass cultivars at three locations. Data are the least squares means of 2 yr at each location.

Origin	Accession or cultivar	Big Flats	Beltsville	Rock Springs
		— g kg^{-1} dry matter —		
Maryland	9085137	188	261	
	9085141	182	250	151
	9085127	182	238	140
	Mean	184	250	146
New Jersey	NJPMC	274	276	198
New York	9051780	188	260	161
	9051781	194	253	158
	9051783	194	262	160
	9051784	188	261	143
	9051785	204	229	146
	9051786	210	266	164
	Mean	196	255	155
Vermont	9051777	186	256	149
	9051778	194	249	147
	9051779	199	277	149
	Mean	193	261	148
Elymus checks	Commercial ecotype	185	244	151
	Omaha	175	233	139
	Mean	180	235	145
Orchardgrass	Pennlate	162	242	127
	Potomac	158	240	126
	Mean	160	241	126
Elymus mean		196	254	154
SE		5.5	5.1	4.2
	Contrasts†			
Elymus vs. orchardgrass		**	**	**
NY vs. checks		**	**	**
NJPMC vs. checks		**	**	**
MD vs. checks		NS	*	NS
VT vs. checks		**	**	NS

** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: *Elymus* vs. orchardgrass, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. checks, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. checks, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. checks, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. checks, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

entries. This was mainly because orchardgrass was more mature (inflorescence emergence to full peduncle emergence) at harvest then *Elymus* (sheath and internode elongation stages; data not shown).

Within *Elymus* accessions, the commercial ecotype and Omaha cultivar had higher NDF concentrations than the *Elymus* accessions from Maryland and Vermont (Table 2). The differences of Vermont accessions were due mainly to accession 9051779. The NJPMC accession had lower NDF than the commercial ecotype and Omaha cultivar at Big Flats and Rock Springs. The New Jersey and New York accessions generally had a greater CP concentration than the commercial ecotype and Omaha (Table 3). The Vermont accessions (due to 9051779) had greater CP than the *Elymus* checks at Big Flats and Beltsville but not at Rock Springs. Differences among accessions in dNDF were not as clear cut (Table 4). Consistent with results for NDF and CP, the NJPMC accession frequently had higher dNDF than the commercial ecotype or Omaha cultivar. The Vermont accessions (influenced mainly by accession 9051779) had higher dNDF than the commercial ecotype or cultivar at Big Flats and Beltsville. Spearman rank correlations among locations and years for NDF were highly positive and significant (Table 5). Crude protein concentrations at Rock Springs in 2002 were not significantly related to most other locations or years. Fewer than one-half of the Spearman rank correlations of dNDF were statistically significant.

Some inconsistency in nutritive value data may have resulted from tillering differences among *Elymus* accessions and the orchardgrass cultivars. Some accessions produced fewer tillers in 2002 than in 2001, and the orchardgrass cultivars produced more tillers than *Elymus* (orchardgrass averaged 120 tillers per plant, whereas the *Elymus* accessions averaged 94 tillers per plant averaged across years; Sanderson et al., 2004). Concentrations of dNDF were not different between *Elymus* and orchardgrass at Beltsville perhaps because orchardgrass produced more vegetative tillers per plant than did *Elymus* (Sanderson et al., 2004), which may have affected relative nutritive value differences between species.

Differences in nutritive value among *Elymus* accessions were probably due to differences in plant morphology, specifically LSR (Table 6; Sanderson et al., 2004). Concentrations of NDF were negatively correlated with LSR in each year and each location, whereas CP and dNDF were positively correlated with LSR (except dNDF at Rock Springs in 2001; Table 7). Correlations

Table 4. Concentrations of digestible neutral detergent fiber in Virginia wildrye accessions and two orchardgrass cultivars at three locations. Data are the least squares means of 2 yr at each location.

Origin	Accession or cultivar	Big Flats	Beltsville	Rock Springs
		g kg^{-1} NDF		
Maryland	9085137	677	760	
	9085141	642	751	654
	9085127	658	742	668
	Mean	659	751	661
New Jersey	NJPMC	767	763	719
New York	9051780	654	745	661
	9051781	636	726	656
	9051783	644	750	658
	9051784	642	762	640
	9051785	636	682	612
	9051786	678	769	685
	Mean	648	739	652
Vermont	9051777	651	766	652
	9051778	638	712	638
	9051779	704	814	723
	Mean	664	764	671
Elymus checks	Commercial ecotype	631	722	651
	Omaha	671	752	700
	Mean	651	737	676
Orchardgrass	Pennlate	659	758	659
	Potomac	626	758	643
	Mean	642	758	651
Elymus mean		678	754	676
SE		6.8	8.2	9.5
	Contrasts†			
Elymus vs. orchardgrass		**	NS	*
NY vs. checks		NS	NS	NS
NJPMC vs. checks		**	**	NS
MD vs. checks		NS	NS	NS
VT vs. checks		*	**	NS

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: *Elymus* vs. orchardgrass, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. checks, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. checks, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. checks, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. checks, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

Table 5. Spearman rank correlation coefficients among locations and years for means of neutral detergent fiber, crude protein, and digestible neutral detergent fiber (n = 17).

	Big Flats 2002	Beltsville 2001	Beltsville 2002	Rock Springs 2001	Rock Springs 2002
	Neutral detergent fiber				
Big Flats 2001	0.94**	0.76**	0.79**	0.88**	0.87**
Big Flats 2002		0.79**	0.75**	0.82**	0.91**
Beltsville 2001			0.72**	0.85**	0.55**
Beltsville 2002				0.73**	0.64**
Rock Springs 2001					0.71**
	Crude protein				
Big Flats 2001	0.45	0.48	0.50*	0.70**	0.46
Big Flats 2002		0.75**	0.76**	0.73**	0.68**
Beltsville 2001			0.70**	0.79**	0.48
Beltsville 2002				0.68**	0.46
Rock Springs 2001					0.54*
	Digestible neutral detergent fiber				
Big Flats 2001	0.65**	0.15	0.40	0.47	0.70**
Big Flats 2002		0.34	0.58*	0.76**	0.67**
Beltsville 2001			0.48	0.39	0.08
Beltsville 2002				0.62**	0.23
Rock Springs 2001					0.46

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.

Table 6. Leaf-to-stem mass ratio in Virginia wildrye accessions and two orchardgrass cultivars at three locations. Data are the least squares means of 2 yr at each location.

Origin	Accession or cultivar	Big Flats	Beltsville	Rock Springs
		Leaf-to-stem mass ratio		
Maryland	9085137	0.75	1.33	
	9085141	0.82	1.09	0.72
	9085127	0.76	0.96	0.78
	Mean	0.78	1.13	0.75
New Jersey	NJPMC	1.22	1.42	1.19
New York	9051780	0.70	1.33	0.87
	9051781	0.88	1.18	0.97
	9051783	0.78	1.40	0.91
	9051784	0.73	1.59	0.80
	9051785	0.84	1.01	0.85
	9051786	0.80	1.23	0.85
	Mean	0.79	1.29	0.88
Vermont	9051777	0.75	1.52	0.85
	9051778	0.86	1.22	0.93
	9051779	0.89	1.91	1.02
	Mean	0.83	1.55	0.93
Elymus checks	Commercial ecotype	0.68	1.08	0.76
	Omaha	0.74	1.20	0.75
	Mean	0.71	1.14	0.76
Orchardgrass	Pennlate	0.54	1.30	0.62
	Potomac	0.58	1.09	0.59
	Mean	0.56	1.20	0.61
Elymus mean		0.81	1.30	0.88
SE		0.05	0.21	0.06
	Contrasts†			
Elymus vs. orchardgrass		**	NS	**
NY vs. checks		*	NS	**
NJPMC vs. checks		**	NS	**
MD vs. checks		NS	NS	NS
VT vs. checks		* *	**	**

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† Contrasts were: *Elymus* vs. orchardgrass, average of *Elymus* entries vs. average of orchardgrass cultivars; NY vs. checks, average of New York accessions vs. average of Omaha and the commercial ecotype; NJPMC vs. checks, NJPMC vs. average of Omaha and the commercial ecotype; MD vs. checks, average of Maryland accessions vs. average of Omaha and the commercial ecotype; and VT vs. checks, average of Vermont accessions vs. average of Omaha and the commercial ecotype.

of NDF with LSR ranged from −0.26 to −0.74 at Rock Springs. Correlations were of similar ranges for CP and dNDF with LSR. Thus, although *Elymus* accessions were estimated visually to be similar in maturity stage at each location, leaf and stem proportions differed enough to affect nutritive value. Grass leaves generally are lower in fiber and higher in digestibility than stems, thus a greater LSR should result in greater nutritive value. In other forage crops, such as alfalfa (*Medicago sativa* L.), selection for improved nutritive value altered LSR (Kephart et al., 1989).

Neutral detergent fiber was positively correlated with leaf length at each location in each year (Table 7). Longer leaves probably required more structural tissue, which is lower in nutritive value. Leaf width was correlated with nutritive value constituents in only a few instances. At Big Flats, CP and dNDF were positively correlated with leaf width in 2001, whereas NDF was negatively correlated with leaf width in both years. Leaf width was negatively correlated with NDF at Beltsville and Rock Springs in 2001 and positively correlated with dNDF in both years at Beltsville. These correlations are consistent with the results of MacAdam and Mayland (2003) who found a negative correlation of leaf width

Table 7. Pearson correlation coefficients among nutritive value and leaf morphological attributes of Virginia wildrye accessions and orchardgrass cultivars at three locations during two years†. Leaf area, length, width, and specific leaf area data were reported in Sanderson et al. (2004). There were 68 observations at each location and year except for Rock Springs in 2002 when there were 56.

Leaf attribute	NDF	CP	dNDF	NDF	CP	dNDF
	Big Flats 2001			Big Flats 2002		
Leaf-to-stem mass ratio	−0.54**	0.66**	0.47**	−0.62**	0.80**	0.61**
Area	−0.04	0.33*	0.38**	0.47*	−0.17	0.04
Length	0.27*	0.08	0.13	0.72**	−0.26*	−0.06
Width	−0.35**	0.41*	0.39*	−0.32*	−0.04	0.16
Specific leaf area	0.03	−0.01	−0.07	0.05	−0.05	−0.06
	Beltsville 2001			Beltsville 2002		
Leaf-to-stem mass ratio	−0.52**	0.47**	0.58**	−0.31**	0.36**	0.44**
Area	0.29*	0.42	0.24*	0.43**	0.10	0.03
Length	0.47**	0.08	0.20	0.62**	0.08	−0.08
Width	−0.28**	−0.05	0.29*	−0.01	0.22	0.24*
Specific leaf area	0.06	0.33*	−0.16	0.28**	−0.10	−0.22
	Rock Springs 2001			Rock Springs 2002		
Leaf-to-stem mass ratio	−0.26*	0.47**	0.19	−0.74**	0.68**	0.74**
Area	0.05	0.20	−0.11	0.67**	−0.44**	0.23
Length	0.35**	0.14	−0.24*	0.86*	0.47**	−0.37**
Width	−0.30*	−0.02	0.07	−0.11	0.10	0.18
Specific leaf area	0.25*	−0.18	−0.30**	0.38**	−0.11	−0.34*

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
NS, not significant.
† NDF, neutral detergent fiber; CP, crude protein; dNDF, in vitro digestible NDF.

with leaf tensile strength in tall fescue. They reasoned that wide leaves had a greater distance between veins and therefore more mesophyll tissue volume and less structural tissue than narrow leaves. Thus, wide leaves probably would have lower fiber concentrations and greater digestibility than narrow leaves. Leaf width was positively related to preference by grazing cattle (MacAdam and Mayland, 2003). In smooth bromegrasss, leaf width was positively associated with acid-pepsin dry matter disappearance (Sleper and Drolsom, 1974). The individual leaf attributes were inconsistently correlated with whole shoot nutritive value indicating that stem development may have controlled whole shoot nutritive value (Hacker and Minson, 1981).

Few other studies have compared nutritive value of Virginia wildrye to allow direct comparison with our results. In Alabama research, crude protein of Virginia wildrye ranged from 230 g kg^{-1} at the vegetative stage to 70 g kg^{-1} at the heading stage, whereas in vitro dry matter digestibility ranged from 800 to 600 g kg^{-1} for the same developmental stages (Bosworth et al., 1985). These values were similar to those for tall fescue (*Festuca arundinacea* Schreb.) in that study.

Crude protein and in vitro dry matter digestibility of Virginia wildrye were higher when grown under tree canopy than when grown in the open (210 vs. 170 g kg^{-1} and 700 vs. 640 g kg^{-1}) in south Texas (East and Felker, 1993). Nitrogen concentration of Virginia wildrye ranged from 19 to 36 g kg^{-1} and in vitro organic matter digestibility ranged from 560 g kg^{-1} for fall regrowth to 630 g kg^{-1} for new spring vegetative growth in Alberta, Canada (Lawrence, 1978).

The nutritive value characteristics of *Elymus* in our study indicate that it is comparable to other cool-season grasses such as orchardgrass and tall fescue and would provide suitable forage for livestock. Our previous research, however, showed that *Elymus* lacked persistence and produced low yields and regrowth relative to commercially available orchardgrass cultivars (Sanderson et al., 2004). These traits would require improvement in *Elymus* to make it a suitable forage grass.

CONCLUSIONS

Virginia wildrye accessions differed in nutritive value principally because of differences in plant morphology. Leaf-to-stem mass ratio appeared to explain most of the variation in nutritive value among Virginia wildrye accessions. Neutral detergent fiber was negatively correlated with LSR, whereas CP and dNDF were positively related to LSR. Differences between *Elymus* and orchardgrass resulted from differences in maturity. Virginia wildrye is comparable to other cool-season grasses in nutritive value.

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